In the past decade, there has been increase interest in the development of microalgae production for increased supplies of renewable fuels. This will help curtail the effects on climate change of increased carbon dioxide (CO2) levels in the atmosphere. With abundant solar energy during photosynthetic activities, microalgae consume CO2 to reproduce their cells and store energy in the form of oils, carbohydrates and proteins. Advantages of microalgae biofuels are greater production yields per land area compared with terrestrial crops such as corn and soybean. Algae culture is the agrarian process of growing and harvesting algae for its many byproducts, including biodiesel. In previous reports the authors have reported on the growth and optimization for commercialization purposes of the microalgae species Scenedesmus obliquus (S. obliquus), which has shown very good properties for use as a biodiesel feed stock. In previous studies the S. obliquus was cultured in a laboratory photobioreactor to determine the efficacy of using biogas as a carbon source for the microalgae’s growth. The biogas contained ~60% CH4 and ~40% CO2, and was derived from an anaerobic digester operating with animal wastes. The results showed that biogas is a viable carbon source for microalgae growth and that significant portions of the biogas’ CO2 can be utilized for algae growth. These results have been used for the basis of designing and constructing a pilot plant anaerobic digester-algae reactor system where food waste have been used as the biodegradable organic substrate. The paper discusses the results obtained from the pilot plant operation to date and provides insights as to how algae production can become a major energy producing crop in Southeast Asia.

Keywords: algae, microalgae culture, algae growth, biogas, anaerobic digesters, climate change, greenhouse gas emissions.

INTRODUCTION

Climate change has been a global concern in the past several decades. A recent Intergovernmental Panel on Climate Change (IPCC) report1 indicated the increase of atmospheric concentration of the greenhouse gases (GHGs) carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O) over the pre-industrial level by 40%, 250% and 20% respectively. Annual average worldwide CO2 emissions from fossil fuel combustion and cement production in 2002-2011 were 8.3 Gt of C12 which is equivalent to 30.4 Gt of CO2 with an average growth rate of 3.2% yr-1. CO2 emissions from energy consumption continue to rise. If the trend continues in the same trajectory, the average global temperature will increase approximately 6 °C in the long term 2. Low carbon energy technologies are required to significantly reduce CO2 emissions. Carbon capture, and storage (CCUS) is one of the important measures to curb global CO2 emission.

One major contributor to global greenhouse gas increases is the degradation of organic wastes, of which food wastes are a major component. Food waste management has become a serious environmental problem. According to the United States Environmental Protection Agency3, landfills are the third largest source of methane in the atmosphere and currently in the United States 95% of the food waste is landfilled. Food waste represents one of the greatest opportunities for the generation of renewable fuels and also one of the least utilized of all organic waste materials. A report from the United Nations’ Food and Agriculture Organization4 shows that global food waste is the world’s third-biggest emitter of greenhouse gases from landfills, behind only the United States and China, releasing the equivalent of more than 3.6 billion tons of carbon dioxide into the atmosphere from the release of methane. Only about 2.5% of food waste is currently recycled in the U.S. and the principal technology is composting, which does provide an alternative to landfilling food waste, but requires large land area, produces smog precursor VOCs, emits carbon dioxide to the atmosphere, and consumes energy. Diverting food waste from landfills can contribute to producing significant quantities of renewable fuels while achieving reducing greenhouse gas emissions. Previous studies by our research group compared the global warming, acidification and eutrophication potentials of composting and anaerobic digestion. Among these two popular options of diverting food wastes from landfills, anaerobic digestion was found to be the most beneficial in terms of greenhouse gas reduction.

Anaerobic digestion is a biochemical process in which complex organic matter (here food waste) are decomposed by heterotrophic bacteria in the absence of oxygen to produce biogas. Anaerobic digestion of food waste is advantageous because the biogas produced is a clean and renewable form of energy. It contains about 60% methane and 40 % carbon dioxide and can be locally used for heating and electricity generation. The biogas is also an excellent substitute for natural gas which is otherwise obtained from hydraulic fracturing. The food waste after the digestion process (called the digestate) has high nutrient value which can be used as a soil amendment in the place of synthetic chemical fertilizers. Microalgae species are aquatic organisms (see Figure 1) that produce complex organic compounds from simple inorganic molecules using carbon dioxide (CO2) as their carbon source, and energy primarily from sunlight (photosynthesis). They

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ABSTRACT

OPTIMIZING ALGAE CULTURE FOR THE PRODUCTION OF BIOFUELS
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www.giapjournals.org/bioevolution.html
produce lipids which are organic compounds containing fats, oils, and related substances that, along with proteins and carbohydrates, are the structural components of living cells. Some species of algae consist of as much as 80% of their mass as lipid content. They have rapid growth rates and can double in mass every 24 hours.

Figure 1: microalgae

A byproduct of their metabolic and reproduction cycles is the production of oxygen (O$_2$) and hydroxyl ion (OH$^{-}$) which increases the solution pH with time if not neutralized with the addition of absorbed CO$_2$. This coupled with their rapid growth rates makes them ideal candidates for the production of alternative fuels (biofuels), especially biodiesel and solid fuels, from the biomass media. In addition, algae contains ~23,500 kJ/kg, has no chlorine, little or no sulfur or heavy metals, is non-toxic, and its biofuel is highly biodegradable. In addition, researchers have recently reported that a life-cycle analysis of pilot-scale operations at an algae-to-fuel facility show that substantial reductions in greenhouse gases will be achieved over petroleum based fuels along with a sustainable energy return when algaeculture (the commercial production of algae) is fully developed. They also found that algae-based fuels from the pilot plant are on par with commercial-scale, first-generation biofuels. The study concluded that greenhouse gas reductions and energy returns are set to increase significantly once economies of scale in production take hold.

PILOT PLANT AT THE UNIVERSITY OF CINCINNATI

A pilot renewable energy project has been designed and constructed at the University of Cincinnati (UC) USA, to study the integration of these two technologies – anaerobic digestion of food wastes to produce biogas, and the production of microalgae utilizing the biogas CO$_2$ content. The anaerobic digester has been designed to convert food wastes from the UC cafeterias into usable energy, including biogas, liquid and solid fuels, as well as fertilizer solids. UC is currently generating approximately 1800 kg of food waste per week of which the majority is landfilled. Food waste is the single largest category of solid waste (MSW) being landfilled comprising > 15% of total MSW in the U.S. The technical approach has been to build a pilot on-campus dry anaerobic digester coupled with an algae photobioreactor that will result in significant volumes of near-pipeline quality methane along with the production of biodiesel and solid fuels from the growth of algae. The technical advantages of this approach include:

- Provides a source of methane that could be used for power production or used by industry;
- Potential for the use for carbon dioxide from the biogas to grow algae for the production of solid fuels, biodiesel, food products, and other products, thereby eliminating the release of this greenhouse gas directly into the atmosphere;
- Utilizes waste carbon sources in a manner that reduces the water requirement for energy production;
- Reduces climate change by recycling and utilizing huge amounts of methane and carbon dioxide which would otherwise be released into the atmosphere from landfills;
- Reduces the potential for groundwater and surface water contamination from landfills;
- Potential for producing biosolids that can be used as fertilizers; and,

REVIEW OF THE PROCESS

The technology is based on many years of industrial and basic research conducted by the authors. It incorporates combining the technologies of anaerobic digestion of organic substrates, with algae production for the continuous harvesting of large quantities of algae for biodiesel production (or other valuable products).

Anaerobic Digester

The pilot plant anaerobic digester utilizes a dry plug-flow type anaerobic digester that is fed with food waste obtained from the University of Cincinnati’s cafeteria. Advantages of a dry digestion process are that no addition of water is needed, which in turn significantly reduces the tank volume required for the process and the generation of wastewater that needs to be treated. Research studies indicate that minimally mixed systems produce about 12.5 % more biogas over continuously
mixed systems. But currently most of the studies in the USA for food waste digestion are done in completely mixed wet reactors. Therefore, a plug flow type reactor configuration without a mixer has been chosen to maximize biogas production.

The anaerobic bioreactor (Figure 2) has a volume of 755 litres (200 gallons) and is equipped to handle a continuous load of about 13.5 kilograms of food waste per day. Initially, the food waste is inoculated with sludge obtained from an anaerobic digester at a local wastewater treatment plant. The food waste is shredded to particle size less than 1.3 cm using a custom made solid waste shredder (Figure 3). It is then mixed with 3 parts of the digestate as a source of inoculum and fed into the digester. The biogas is collected from the top and passed through a wet-tip gas meter before stored in a polyethylene bag. Fittings like sampling septum, control valve, etc., are also provided in route. The bioreactor is maintained at mesophilic temperature (32 ± 3 °C) in an environmental control chamber with a solids residence time (SRT) of 15 days. Operating parameters like pH, total solids (TS), volatile solids (VS), moisture content, gas production and gas composition (CH$_4$ and CO$_2$) are monitored daily. Accumulation of volatile fatty acids and ammonia over 1.5 g/L and 3.78 g/L, respectively, can potentially inhibit the digestion process. Hence volatile fatty acids (VFA) and ammonia nitrogen (AN) are monitored regularly to ensure stable digestion conditions. The reactor is currently approaching steady state conditions.

![Figure 2: Anaerobic Bioreactor](image)

**Algae Production System**

The biogas from the anaerobic digester described above is stored in a 5 m$^3$ bag (Figure 4). This biogas is the CO$_2$ source for the algae scrubber (background of Figure 4) where the CO$_2$ is scrubbed and the methane which exists the top of the scrubber is also stored in a 5 m$^3$ bag. (Figure 4). The pilot plant algae production technology utilizes inexpensive closed, continuously cleaned UV stabilized polyethylene tanks (Figure 5) that are readily available and less than 1/5 – 1/4 the cost of the closed photobioreactors mentioned in previous studies. They operate under completely mixed operation meaning they can be easily drained and repaired if necessary, and/or replaced without interrupting the production significantly. The technology’s capital investment costs are significantly reduced by using readily available and inexpensive closed top polypropylene tanks instead of other types of photobioreactors. These tanks are used in series as completely mixed tank reactors which saves space and further reduces costs. In addition, by using CO$_2$ from biogas we will maximize the production rate of algae (kg/m$^2$) since biogas has the highest concentration of CO$_2$ of any readily available and environmentally friendly source.

![Figure 3: Food Waste Shredder](image)

We are developing this technology because current production rates of algae utilizing ambient concentrations of CO$_2$ as the carbon source are too low for commercialization purposes. Also, utilizing CO$_2$ from combustion flue gases (e.g., from coal and/or oil and natural gas combustion) is impractical because of the low concentration and the presence of acid gases (at
even trace amounts). Coupling algae production with the anaerobic digestion of organic wastes, such as food wastes, provides a reliable high concentration of CO₂ gas that can be used in innovative reactors for optimizing the high growth rate of algae needed to be commercially viable.

![Figure 4: Biogas and CH₄ Storage Bags](image)

The microalgae being utilized is *Scenedesmus obliquus* as it has been found to be very resistant to contamination and has a reasonably high lipid concentration with a high level of triglycerides (TAGs). The microalgae is grown in continuously cleaned, UV stabilized, closed top, inexpensive polyethylene continuous flow, stirred tank reactors (CFSTRs) utilizing the carbon dioxide gas in the biogas as the algae carbon source. Two equal volume CFSTRs in series provide the daytime growth cycle whose residence time is automatically set to correspond to the daylight period of the site’s location. A 3rd conical-bottom tank acts as a dwell tank where initial settling of the algae takes place. The partially settled algae is sent to a hydroclone for additional separation and settling where the partially cleaned top flow is sent to a bubble scrubber where the algae is allowed to contact the biogas. The bottom cut of the hydroclone which has a higher concentration of algae is continuously sent to a filter and/or a centrifuge where the algae is concentrated to 30% solids. The extracted water from the filter or centrifuge is recycled to the 3rd algae tank for reuse. The algae cake is air dried in at the present time and the dried algae is processed for lipid extraction and transesterification is used to produce biodiesel.

![Figure 5: Algae growth tanks](image)

The technical advantages of this approach include:

a) Closed tanks with no open access for the dissolved CO₂ to escape to the atmosphere – almost complete carbon utilization;

b) Use of continuously cleaned, closed top CFSTRs instead of more expensive and difficult to operate and clean plug flow reactors (PFRs);

c) The land space requirement for using CFSTRs compared to raceway systems will be reduced by 94%;
d) Potential for the use for carbon dioxide from biogas which has the largest concentration of CO₂ gas to grow algae for the production of solid fuels, biodiesel, food products, and other products;

e) Biogas contains little or no acid gas components, thus no pretreatment is needed to prevent significant pH drops from the absorption of SO₂, NOₓ, or HCl as from using combustion flue gases;

f) Biogas contains trace amounts of NH₃ and H₂S which are both nutrients and generally offset each other in terms of pH in solution;

From an analysis of typical food wastes it is typically possible to generate ~13.3 m³ of methane and 0.167 liters of biodiesel per day per 100 kg of as-received food waste. This would represent a potential generation of 1.593 x 10¹² m³ of methane and 2 x 10¹¹ liters (5.29 x 10¹⁰ gal) of biodiesel per year for the 36 million tons of food waste disposed of every year in the USA. We anticipate the cost per gallon of biodiesel will meet the US Department of Energy goal of $5 per gallon equivalent because of the very low capital and operating costs associated with the technology.

**POTENTIAL FOR THAILAND**

Various regions of Thailand offer significant advantages for the future development of this integrated technology.

**Optimum meteorological conditions:**

Anaerobic digestion and algae culture would benefit by being developed in those areas of the world where more optimum and thus, economical, conditions exist, especially related to meteorology. The region of earth between the Tropics of Cancer and Capricorn (± 23.5° Latitude) has the highest average value of solar insolation (~9.3 kW-hr/m²-day), and an average amount of sunlight of ~12 hours per day, meaning that higher photosynthetic rates to utilize the CO₂ are readily available. In addition, significant agricultural activities offer the most favorable sources of organic wastes for the development of large-scale anaerobic digester systems. For example, the Northeastern region (Essan) of Thailand has abundant agricultural activities including poultry and swine production, as well as other biomass sources which are well suited for anaerobic digestion.

**Significant existing expertise with anaerobic digester designs:**

Many faculty at Thai universities have significant expertise in the design of industrial anaerobic digesters which could be utilized for the integrated development of this technology. For example, the faculty at Khon Kaen University have developed modern anaerobic digesters for processing animal and agricultural wastes that would be necessary for a project of this type.

**The country’s imminent repercussions from climate change:**

Climate change affects Thailand in drastic ways. The devastating effects of global climate change are well documented and widely discussed. In Thailand, higher surface temperatures, frequent droughts, and rising sea levels threaten the country’s main export—rice—and according to a Thai official⁷, could submerge the capital, Bangkok, within 20 years. For this reason, it is an ideal location not only for research, but also for applying this research to affect major change in the manner in which organic substrates are managed.

**REFERENCES**


